FUPRE Journal of Scientific and Industrial Research
Vol.4, (2), 2020
ISSN: 2579-1184 (Print) ISSN: 2578-1129 (Online)

Synergistic Effect of Natural and Synthetic Polymers as Drag Reducing Agents in Water Flow: Effect of Pipe Diameter

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Abstract

The pressure losses accompanying pipeline turbulent water flow is one of the major challenges in process industries, which requires high pumping energy. Addition of minute quantities of high molecular weight polymeric additives in parts per million (ppm) reduces pumping cost and pressure losses. In this present work, an experimental flow facility which consists of liquids storage tanks, pumps and unplasticised polyvinylchloride (uPVC) horizontal pipe system has been constructed. DR in single-phase water flow was investigated using partially hydrolyzed polyacrylamide (HPAM; magnafloc 1011), polyethylene oxide (PEO) and Aloe Vera mucilage (AVM) separately, as well as mixture of HPAM-AVM and PEO-AVM at different flow rate (Q) in two different pipe diameters (0.012 and 0.02 m ID). Master solution of 2000 ppm and 20000 ppm for HPAM, PEO and AVM respectively and their respective mixtures was used at different concentrations. U-tube manometer was used to measure the pressure drop. Drag reduction (DR) of 73.6%, 76%, 64% for HPAM, PEO and AVM; 80% and 84% for HPAM-AVM; 81.6% and 84.8% for PEO-AVM at mixing ratio of 3:1 and 1:19 in 0.012 m ID was found to be higher than DR obtained in the larger pipe at the same conditions. From the experimental results, it is obvious that at same concentration, polymer type and flow rate DR increased with decrease in the pipe diameter.

Keywords: **Drag reduction; polymers; polymer mixture; pipe diameter.**

1. Introduction

The turbulent mode of transporting liquids in pipelines over long distances in process industries is one of the most energy consuming segments. Different turbulent structures (eddies) formed during the turbulent pipeline transportation of the liquids increase the pressure drop (skin friction, drag) and dissipate pumping energy*(Marmy et al., 2012; Abdulbari et al., 2014; Edomwonyi-Otu and Angeli, 2014; Gimba et al., 2018)*. Addition of small amount in parts per million (ppm) of high molecular weight polymeric solution can lead to large decrease in pressure drop and energy saving known as drag reduction (DR) *(Bewarsdorff and Gyr, 1995; Sellin et al., 1982; Gimba et al., 2017)*. It has found a wide range of application in process industries since it was discovered by Toms in 1948. The Trans-Alaska 1300 km pipeline system in 1979 was the first industrial application where 10 ppm of oil-soluble polymer was used to increase the flow rate. They achieved 50% DR, which eliminate the need of installing additional two pumping stations to boost the throughput from 1.45 to 2.1 million barrel per day. Other application includes marine and biomedical system, crude oil pipeline transportation over a long distances, irrigation, floodwater disposal and sewage, drilling of oil from reservoir, firefighting, Extraction, filtration, heat and mass transfer application *(Abubakar et al., 2014a; Edomwonyi-Otu and Angeli, 2014; Gimba et al., 2019)*. It is also now being suggested for transportation of drinking water because of its harmless properties *(Edomwonyi-Otu and Adelakun, 2018*).

The friction factor is a function of pipe diameter, velocity, density and viscosity for smooth pipelines flows for Newtonian fluids at constant temperature and pressure. The effect of pipe diameter on drag reduction in pipeline flow using drag reducing polymers (DRP) was studied by many researchers *(Virk, 1975; Interthal and Wilski, 1985; Ahmad et al., 2009; Karami and Mowla, 2012; Gimba et al., 2019). Interthal and Wilski, (1985)* were amongst the first to published the effect of drag reducing polymers and pipe diameter on DR. They reported that DR increased (66 – 80%) with increase in pipe diameter (0.003 – 0.014 m internal diameter; ID) and then fall to 76% at the highest pipe diameter (0.03 m ID), indicating lack consistency in their results. *Ahmad et al., (2009)* investigated the effect of Okra mucilage on DR in different pipe sizes (0.015 and 0.025 m ID) in turbulent water flow. They observed that, DR increased (50 – 71%) with decrease in pipe diameter (from 0.025 – 0.015 m ID) at the same conditions. They suggested that, decrease in pipe diameter implies increasing velocity inside the pipe, which increase the degree of turbulence of flow inside the pipe. This creates good interaction between the additive and the turbulent structure (eddies) in the smaller pipe. This was in agreement with the work of *Karami and Mowla, (2012)*, where the also studied DR of three drag reducing polymers in two galvanized iron pipes of 0.0254 and 0.0127 m ID at the same conditions. They also reported that the drag reduction decreased with increase in pipe diameter for all the DRP used. For the polymer mixture, *Dingilian and Ruckenstein (1974)* were the first to use mixtures of PEO, PAM and CMC at different concentrations. They observed a positive synergistic effect on PEO-CMC and PAM-CMC combination and negative effect on PAM-PEO combinations. Drag reduction of the binary polymer system was higher (positive deviation) than the drag reduction caused by each of the polymers when present alone in a solution at the same concentration as in the mixture. They proposed that, to achieve a synergy, at least one polymer or both of the polymers most have rigid structure. This was in agreement with the work of *Parker and Joyce (1974); Dschagarowa and Bochossian (1978);Reddy and Singh (1985); Malhotra et al., (1988); Gustavo and Soares (2016); Andrade et al., (2016);Edomwonyi-Out et al., (2016); Gimba et al., (2019).*

In spite of the enormous works done in understanding the influence of pipe diameter on drag reduction, the literature is still scanty compared to Reynolds number. More data were needed to develop models for the precise prediction of drag reduction in horizontal water pipeline flow than is currently available. Hence, the aim of this work is to provide more data on the study of the effect of pipe diameter on drag reduction using aloe Vera mucilage (AVM), polyethylene oxide (PEO) and partially hydrolyzed polyacrylamide (HPAM) as well as their mixture (HPAM-AVM and PEO-AVM) in a horizontal water flow system.

2. Materials and Methods

2.1 Description of the flow facility

The schematic diagram of the experimental set-up is shown in Figure. 1. The flow facility is divided into three sections which are: the handling section, pumping or regulating section and test section. The handling section consists of water and separator tank with capacity of 200 and 220 liters where the water is stored. The separator tank allows draining of water through the bottom opening. In the regulating or pumping section, two pipe diameters (0.012 and 0.02 m ID) are each connected to water and separator tanks. The centrifugal pumps (model Jet 102M/N.31227) were used to circulate the test fluids into the test section. The globe valves were used to regulate the flow rates which were measured with variable area flow meters (LZM-20J; ±5% accuracy). The valves are located between the pumping section and the test section. The globe valves also regulate the recycle and bypass flows. The water flow meter has maximum flow rate of 100 liters per minute (LPM). The flow meter was calibrated before starting any experiments. The injection port for the polymer master solution is located by the side of the water pipeline before Y-junction. The new Era-programmable peristaltic injection pump (model NE-9000; ±2% accuracy) was used to inject the polymer master solution into the water phase. The test section was made up of straight acrylic pipe of 0.02 m ID and 140 times the diameter of the pipe (140D) long from the Y-junction to the second pressure port. The pressure taps were created by making small holes at the bottom of the acrylic pipe walls at the distance of 140D which provides fully developed flow in the test section. U-tube manometer (Pyrex) and Fann viscometers (model 35A; ±1% accuracy) were used for the measurement of pressure drop and viscosity of the polymer solutions respectively.

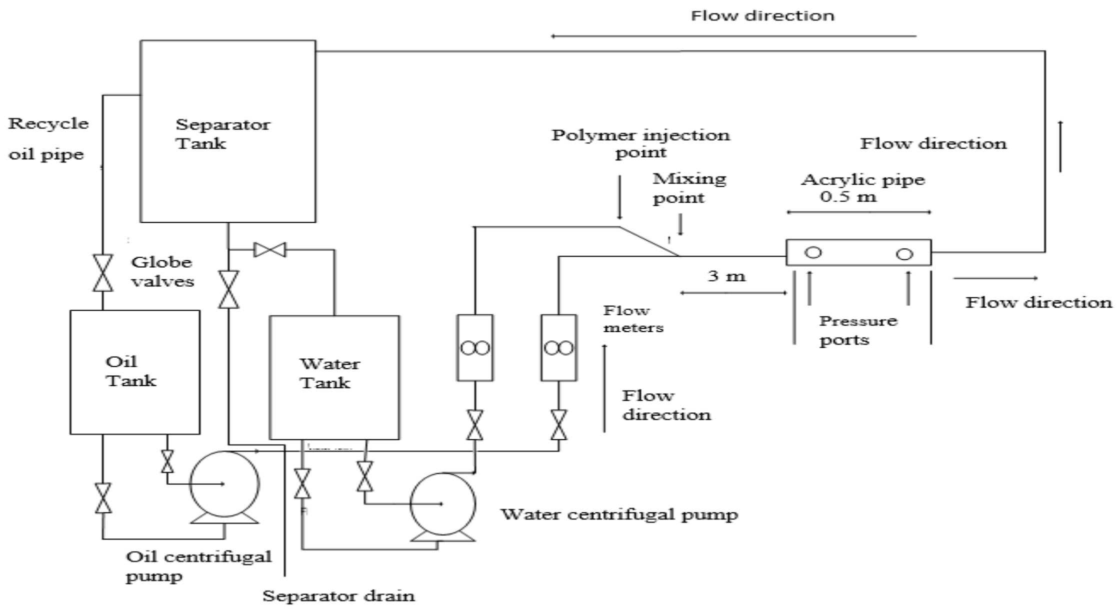

Figure. 1: Schematics of experimental set-up of flow facility

2.2 Polymer Preparation

The polymers used are polyethylene oxide (PEO) manufacture by Sigma-Aldrich with average molecular weight of 8×10^6 g/mol, partially hydrolysed polyacrylamide, HPAM (Magnafloc 1011) manufacture by BASF chemicals 10×10^6 g/mol, and Aloe Vera mucilage (AVM) extracted from Aloe Vera plant. All the polymers are water soluble and were used without further purification. The polymers solutions were prepared individually first, before the polymer mixture solutions were prepared. A master solution of 2000 ppm of each of the synthetic polymer was prepared as follows. 10 g of each of the polymer powder was measured using weighing balance (Kerro, BLC 3002) and gently spread over 5 liters of water surface and stirred for 3 hours with a mechanical stirrer (Gilverson, L28) at a very low speed (to avoid degradation of the polymer) for the mixture to be completely homogenized. The stirred solution was left for 12 hours mostly overnight to ensure complete dissolution of the polymer particles and removal of trapped gas bubbles to form the master solution *(Abubakar et al., 2014a; Edomwonyi-Otu et al., 2015; Gimba et al., 2018).* Aloe Vera leaves were harvested from a garden then washed thoroughly. The leaves were then cut vertically on both sides and soaked in water for 10 minutes, to remove the Aloin within them. The leaves were then peeled and the Aloe Vera mucilage (AVM) was extracted by scraping and sieving the gel from the aloe leaves. Aloe Vera leaf contains about 98% water while the remaining 2% is the AVM

(Gimba et al., 2018). 20,000 ppm master solution of AVM was prepared. After the preliminary experiments with each of the polymer solutions in single-phase water flow, the total concentration (TC) for any mixture was chosen based on the fact that at least one of the polymers in the mixture gave maximum DR at that concentration *(Reddy and Singh, 1985)*. In case of this work, 30 ppm and 400 ppm were selected as the total concentration for the mixture of HPAM-AVM and PEO-AVM. The mixtures master solution of 2000 ppm and 20,000 ppm were prepared at different mixing ratio to achieve the require concentration of the polymer mixtures in the flow line as described by *(Malhotra et al., 1988; Reddy and Singh 1985; Gimba et al., 2018 and 2019)*. The detailed procedure for polymer mixtures preparation has been published in our previous works *(Gimba et al., 2018 and 2019)*.It was injected into the water phase at specific flow rate in order to achieved the require concentration in the water flow line. The mixing of the polymers can also be guided using Equation 1 *(Gustavo and Soares, 2016):*

$$C_a + C_b = 1$$

Where, C_a and C_b are concentration of each of the polymer.

2.3 Experimental Procedure

The flow meters and injection pump was tested before running the experiments to ensure accurate delivery of the required amounts of water and polymer concentration into the test section. The experiment was carried out in two different horizontal pipe diameters (0.012 and 0.02 m ID) at ambient conditions (25 ^{o}C, 1 atm). The pressure drop was measured using the U-tube manometer. Each experimental run was repeated three times and the average of the pressure drop measured before and after the addition of the drag reducing agents (DRAs). HPAM, PEO, AVM, HPAM-AVM and PEO-AVM were tested at different concentration, flow rate and pipe diameters. The concentrations of HPAM and PEO ranging from 2.5 - 100 ppm while the concentration of Aloe Vera mucilage (AVM) ranging from 5 - 500 ppm at flow rates of 0.65 (10 l/min), 1.28 (20 l/min), 1.90 (30 l/min) and 2.46 m^3/hr (40 l/min). The optimal polymer concentration (30 ppm for HPAM and PEO and 400 ppm for AVM) was obtained from our preliminary experiments of single-phase water flow. The optimal concentration was selected to be the total concentration (TC) of the polymer mixture *(Gimba et al., 2019)*.The pressure drop was recorded and used for calculation of drag reduction defined by the given Equation 2.

$$DR = \frac{\Delta P_{WOut} - \Delta P_W}{\Delta P_{WOut}} \times 100\% \quad (1)$$

Where; ΔP_{WOut} and $\Delta P_W$is pressure drop of the fluid without and with DRAs.

3. Results and Discussion

Only average values of the pressure drop obtained from three measurements were used for the calculation of percentage drag reduction as well as the viscosity readings.

The DR calculated using Equation 2 was presented graphically against concentration at different flow rate.

Effect of polymers concentration, flow rate and pipe diameter

The percentage drag reduction of three polymers (HPAM, PEO and AVM) was studied in single-phase water flow (SPF) at different concentrations (2.5 - 100 ppm), flow rate (Q) (0.65, 1.28, 1.90 and 2.46 m^3/h) and pipe diameters. Figures 2-4 show the results of the effect of polymer concentration at different flow rate and pipe diameter on drag reduction in single-phase water flow for HPAM, PEO and AVM. It was observed that DR increased with increase in the polymer concentration and flow rate due to increase in the number of polymer molecules. This increase the interaction of the polymer molecules with the turbulent eddies in the pipeline flow, which brings about drag reduction effectiveness (DRE) and this corroborate with previous findings *(Abubakar et al., 2014b; Edomwonyi-Otu et al., 2015; Virk, 1975)*. It was also observed that at same concentration, polymer type and flow rate, DR increased (70 to 73.6%; 72 to 76% and 50 to 64% for HPAM, PEO and AVM respectively) with decrease in the pipe diameter (from 0.02 – 0.012 m IDs).

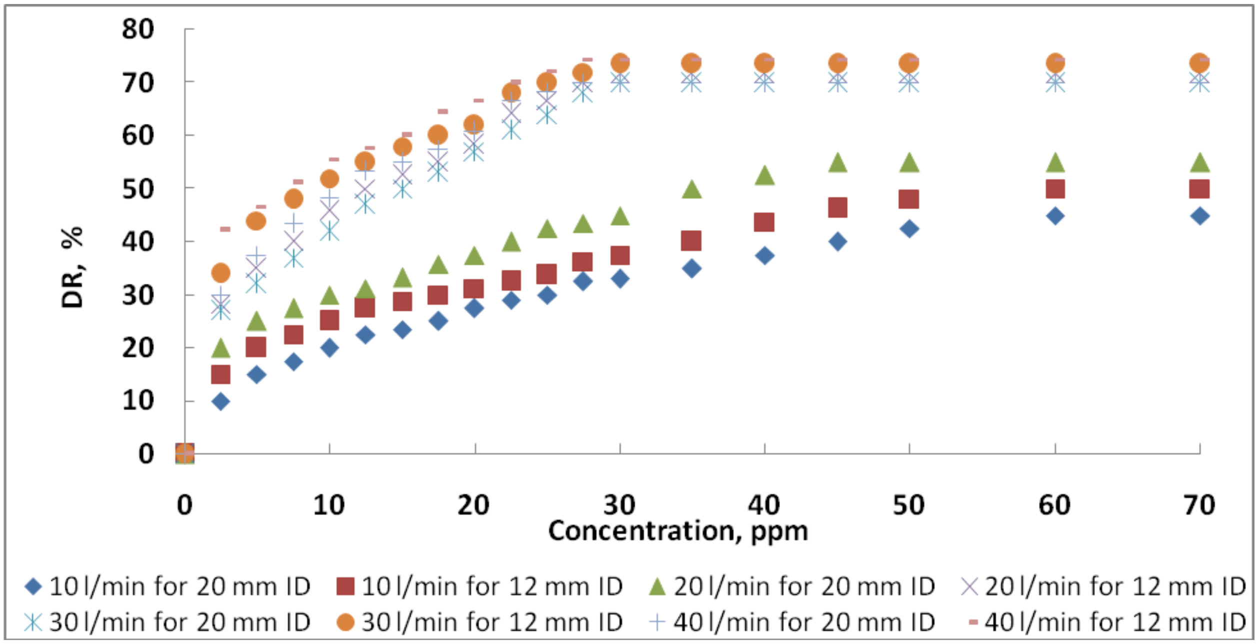

Figure. 2: Effect of polymer concentration on drag reduction in single-phase water flow at different flow rate and pipe diameter (0.012 and 0.02 m ID) for HPAM.

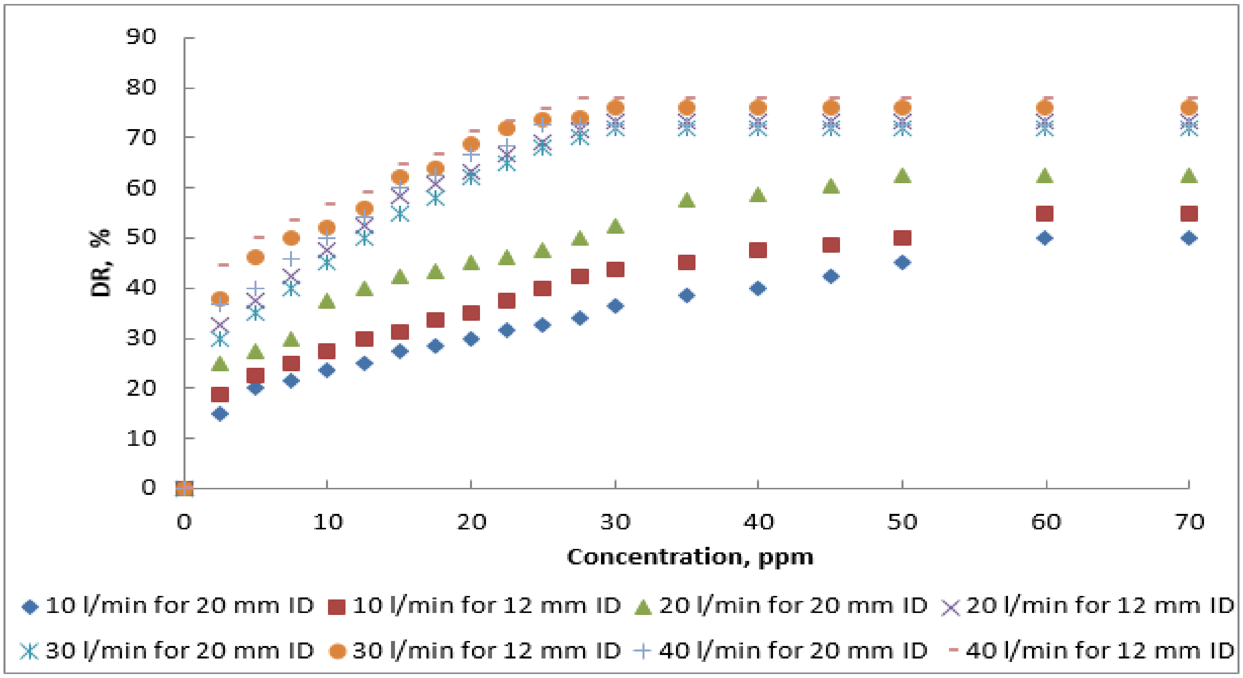

Figure 3: Effect of polymer concentration on drag reduction in single-phase water flow at different flow rate and pipe diameter (0.012 and 0.02 m ID) for PEO.

Reducing the pipe diameter (smaller pipe) implies increasing velocity inside the pipe, resulting to a high pressure drop in the flow due to high degree of turbulence. The high turbulence inside the smaller pipe increased the collision between eddied which result to the formation of smaller eddies. The drag reducing polymers (DRP) easily overcome smaller eddies than larger once, because smaller eddies absorbed lower amount of energy from the flow, which was verified by large numbers of experimental results from the present study. This corroborate with the findings of *Virk, (1975); Interthal and Wilski, (1985); Ahmad et al., (2009); Karami and Mowla, (2012); Gimba et al., (2019).* At lower flow rate, the effect of pipe diameter is clearly noticeable than at higher flow rate where percentage drag reduction values for 0.012 and 0.02 m ID are closed to each other.

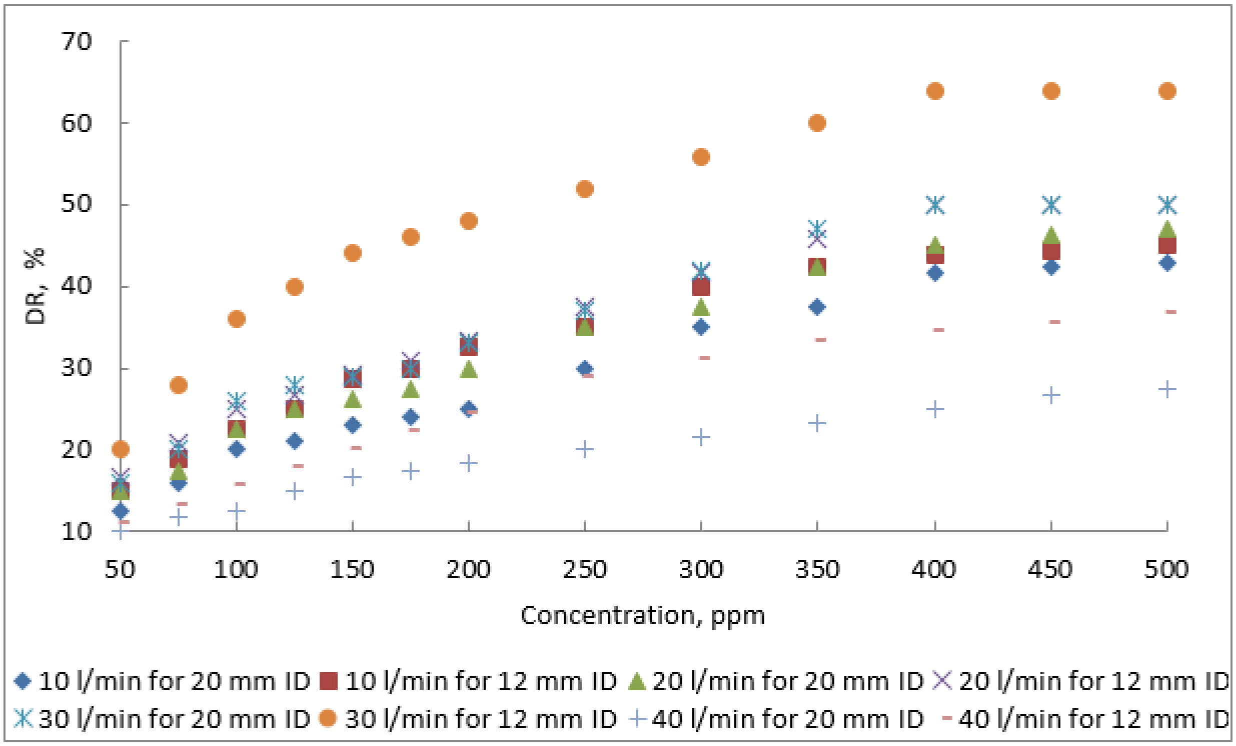

Figure 4: Effect of polymer concentration on drag reduction in single-phase water flow at different flow rate and pipe diameter (0.012 and 0.02 m ID) for AVM.

Effect of polymer mixtures concentration, flow rate and pipe diameter

The percentage drag reduction of two polymer mixtures (HPAM-AVM and PEO-AVM) was studied in single-phase water flow (SPF) at different concentrations, flow rate (0.65, 1.28, 1.90 and 2.46 m^3/hr) and pipe diameters (0.012 and 0.20 m IDs). Figures 5 - 8 show the effect of polymer mixture concentration, flow rate and pipe diameter on drag reduction. It was observed that DR increased with increase in the proportion of HPAM and PEO in the polymer mixtures and flow rate. Similar trend to that of HPAM, PEO & AVM were observed. The DR of 75.2% and 82.5% (HPAM-AVM), 78% and 83% (PEO-AVM) in 0.020 m ID and 80% and 85% (HPAM-AVM), 81.6 and 85.5% (PEO-AVM) in 0.012 m ID was obtained at the mixing proportion of 3:1 and 1:19 for a TC of 30 ppm and 400 ppm. It was also observed that at same conditions, DR increased with decrease in the pipe diameter (from 0.02 – 0.012 m IDs). At lower flow rate, the effect of pipe diameter is clearly noticeable than at higher flow rate where DR values for 0.012 and 0.020 m are closed to each other, which corroborate with the findings of *Virk, (1975); Interthal and Wilski, (1985); Ahmad et al., (2009) and Karami and Mowla, (2012)*. Synergism in DR observed for both of the pipe diameter (0.012 and 0.02 m ID) may be due to the interaction amongst the polymer molecules, which influence the extension of the molecules. It may also be due to increase in the polymer coil dimension and their rigidity. This was in agreement with the previous works *(Dingilian and Ruckenstein 1974; Reddy and Singh, 1985; Malhotra et al., 1988; Gustavo and Soare, 2016)*.

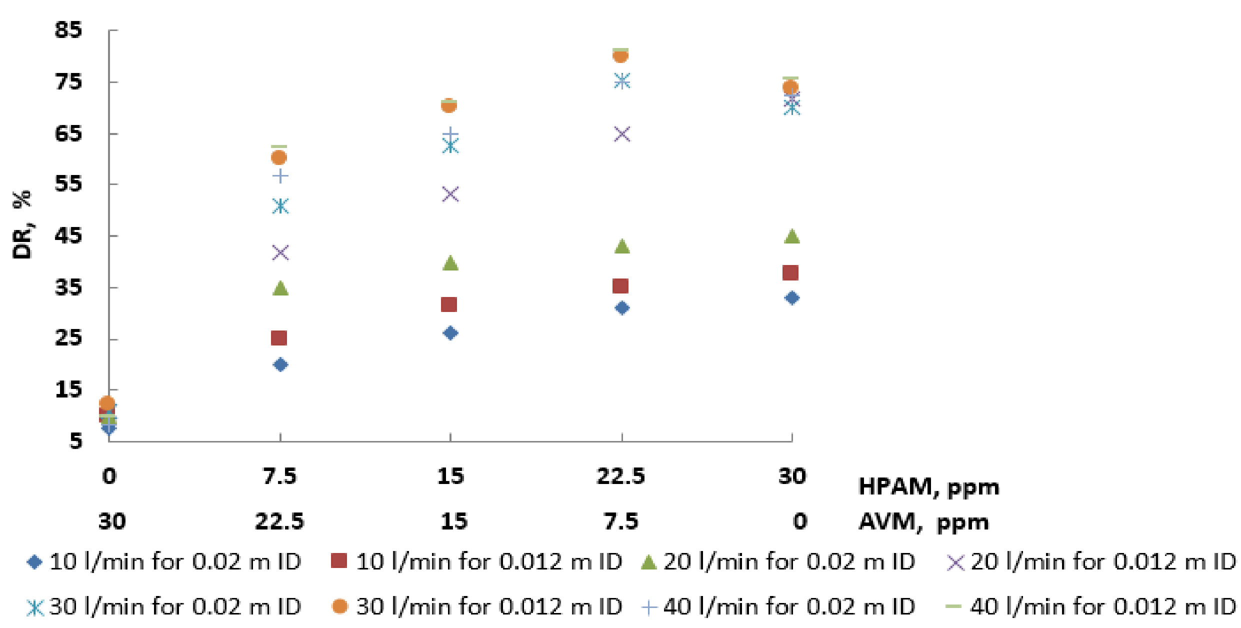

Figure 5: Drag Reduction against mixture concentration (HPAM-AVM) at different flow rate and pipe diameter (0.012 and 0.02 m ID) in single-phase water flow and total concentration of 30 ppm.

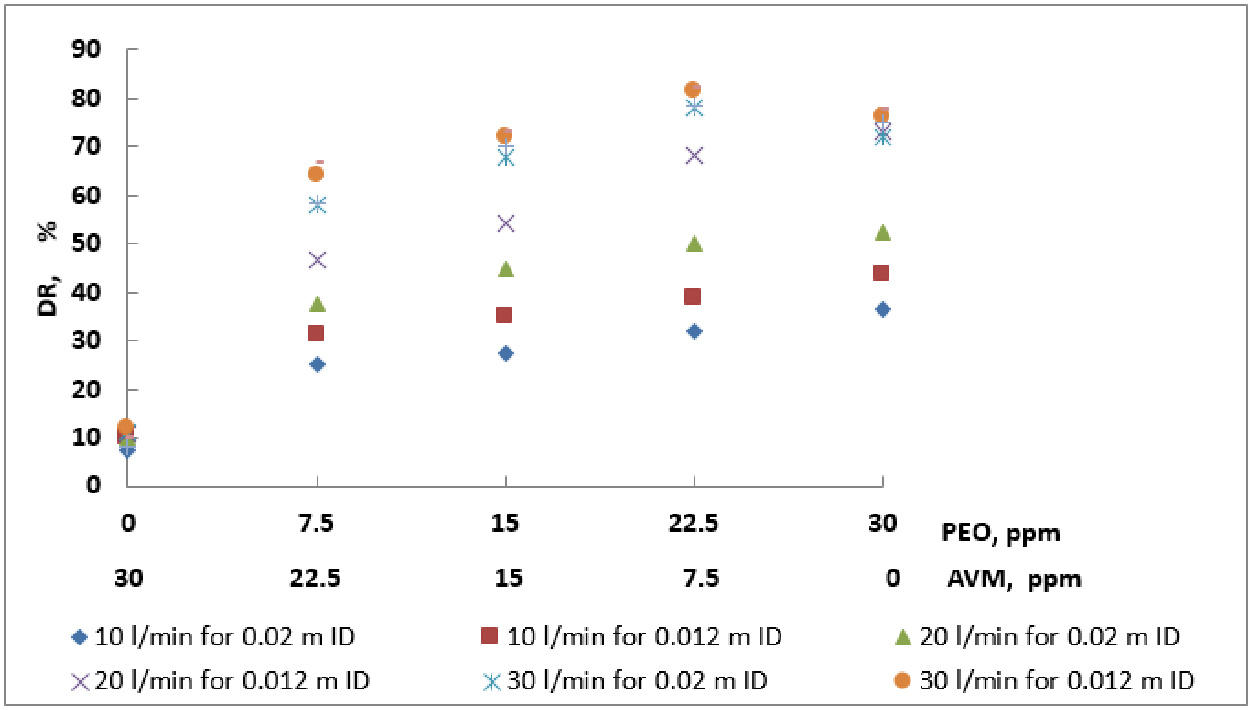

Figure 6: Drag Reduction against mixture concentration (PEO-AVM) at different flow rate and pipe diameter (0.012 and 0.02 m ID) in single-phase water flow and total concentration of 30 ppm.

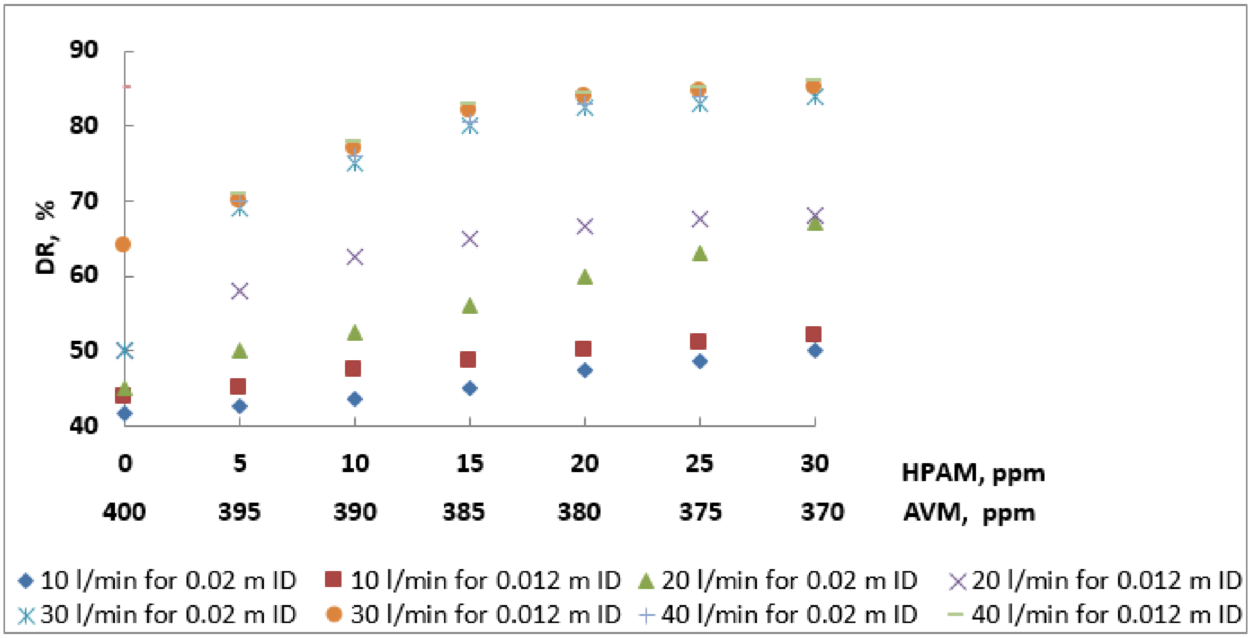

Figure. 7: Drag Reduction against mixture concentration (HPAM-AVM) at different flow rate and pipe diameter (0.012 and 0.02 m ID) in single-phase water flow and total concentration of 400 ppm.

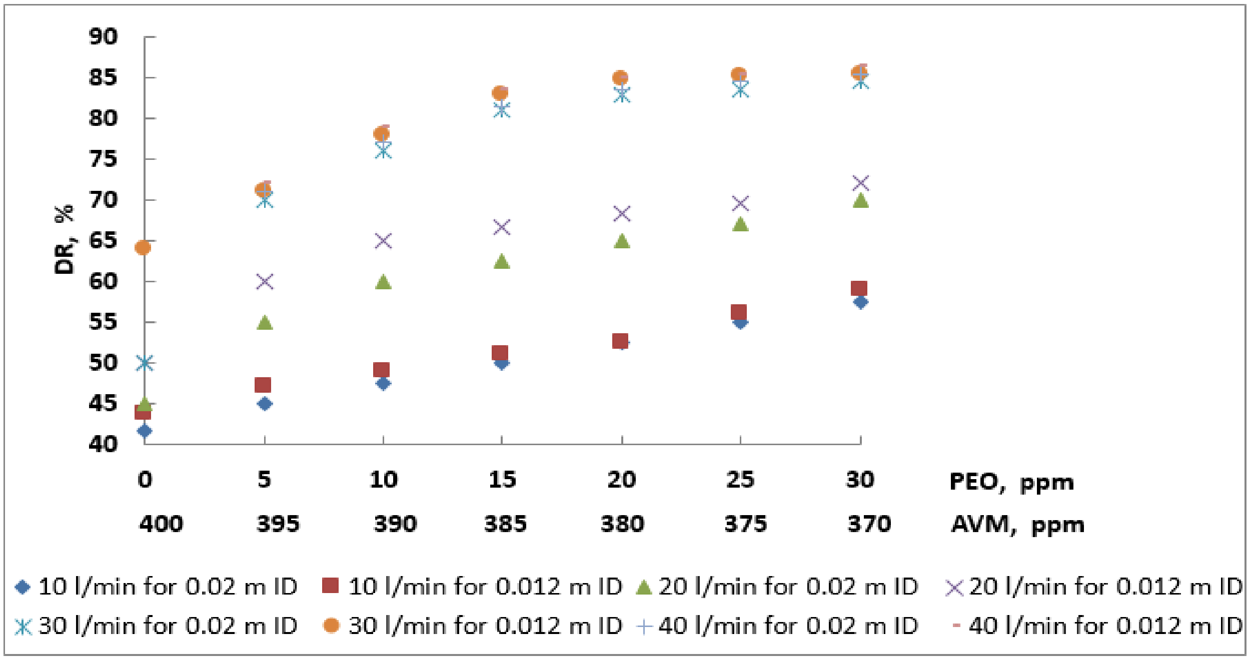

Figure 8: Drag Reduction against mixture concentration (PEO-AVM) at different flow rate and pipe diameter (0.012 and 0.02 m ID) in single-phase water flow and total concentration of 400 ppm.

Conclusions

The synergistic effect of natural and synthetic polymers as drag reducing agents in different size of pipes in single-phase water flow has been studied. From the results obtained, it can be concluded that:

- DR increased with a decrease in pipe diameter and increase with increase in velocity.
- DR is a function of polymer concentration, flow rate and pipe diameter.
- Grafting HPAM and PEO onto AVM enhanced effectiveness of drag reduction of the AVM.
- DR and synergism in DR for the polymer mixtures are functions of concentration and flow rate.

Acknowledgement

The authors would like to thank the members of the multiphase flow and separation systems research group of the Ahmadu Bello University, Zaria, for their moral and technical support.

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